Hot Baryons in Deep Potential Wells

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Topics

X-ray emitting hot gas in elliptical galaxies, groups and clusters of galaxies:

- Gas dynamics – measure bulk motions
- History – turbulence, entropy, metals
- Absolute motion

Gas Dynamics

Major mergers

Minor mergers, sloshing

Rotational support

Large-scale motion around clusters

Galaxy stripping and infall

Con-X Velocity Resolution

Thermal plasma (bapec) with 0.5 solar abundances, 4 eV calorimeter response and perfect calibration.

kT (keV)	count (0.5-7 keV)	v_{turb} (km s^{-1})	σ_{cz} (km s^{-1})	σ_{turb} (km s^{-1})	kT (keV)	count (0.5-7 keV)	v_{turb} (km s^{-1})	σ_{cz} (km s^{-1})	σ_{turb} (km s^{-1})
1	1k	0	67	-	3	1k	0	300	-
1	1k	100	68	<270	3	1k	100	590	<2100
1	1k	300	79	<330	3	1k	300	710	<2700
1	10k	0	9.4	-	3	10k	0	19	-
1	10k	100	9.6	22	3	10k	100	21	48
1	10k	300	14	16	3	10k	300	28	36
1	100k	0	2.1	-	3	100k	0	5.3	-
1	100k	100	2.4	5.5	3	100k	100	6.1	12
1	100k	300	2.6	6.2	3	100k	300	8.5	10

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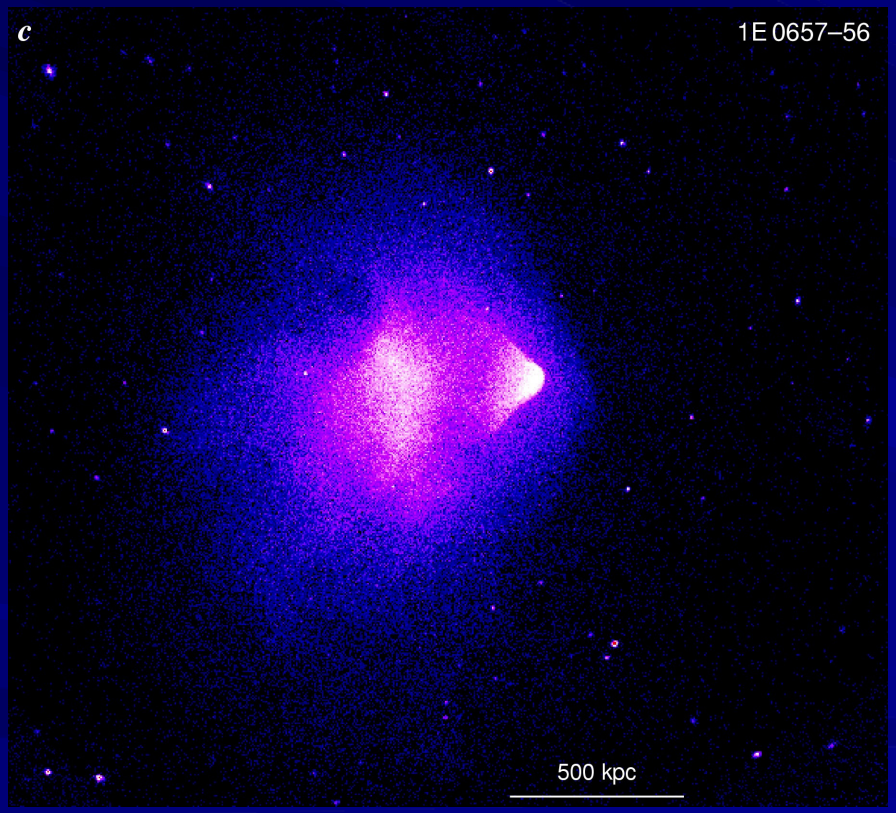
kT (keV)	count (0.5-7 keV)	v_{turb} (km s^{-1})	σ_{cz} (km s^{-1})	σ_{turb} (km s^{-1})	kT (keV)	count (0.5-7 keV)	v_{turb} (km s^{-1})	σ_{cz} (km s^{-1})	σ_{turb} (km s^{-1})
5	1k	0	2300	-	8	1k	0	Unconstr	-
5	1k	100	720	<1400	8	1k	100	Unconstr	Unconstr
5	1k	300	2900	2100	8	1k	300	Unconstr	Unconstr
5	10k	0	40	-	8	10k	0	91	-
5	10k	100	29	<100	8	10k	100	96	<260
5	10k	300	76	150	8	10k	300	93	155
5	100k	0	8.7	-	8	100k	0	12	-
5	100k	100	8.7	19	8	100k	100	14	44
5	100k	300	15	16	8	100k	300	25	28

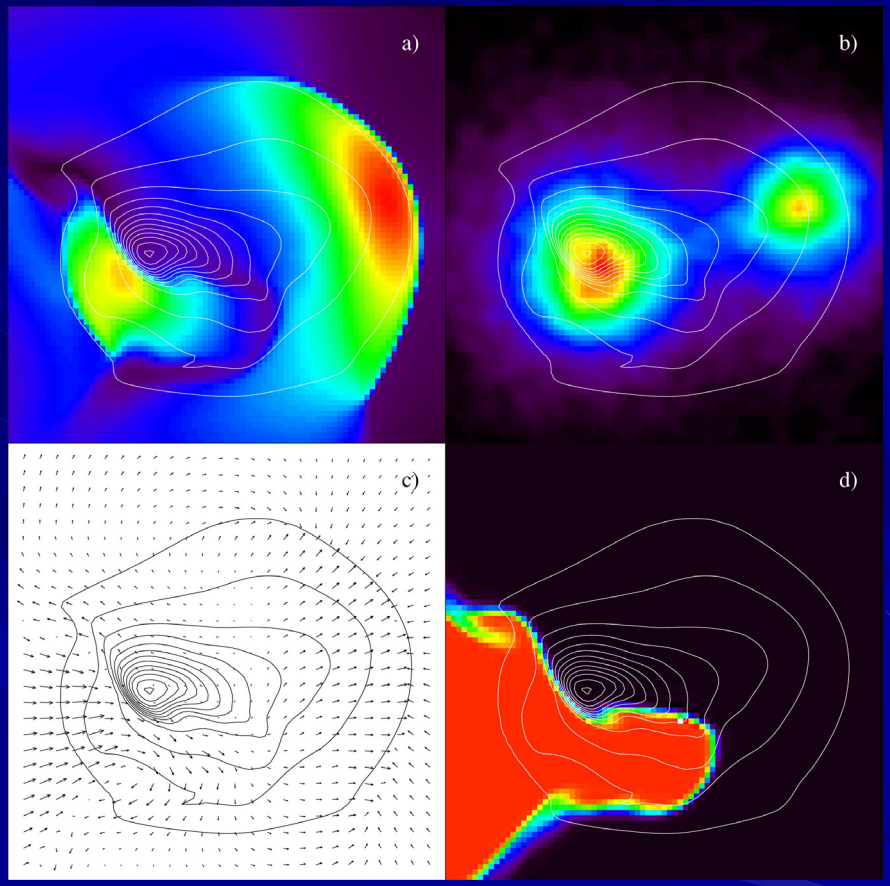
Major Mergers

Large variations in gas velocity, eg 2000-3000 km s^{-1} for the Bullet cluster (Markevitch et al. 2002) – but gas is hot.



kT

Projected DM



v_{max}=1850 km s^{-1}

Identity

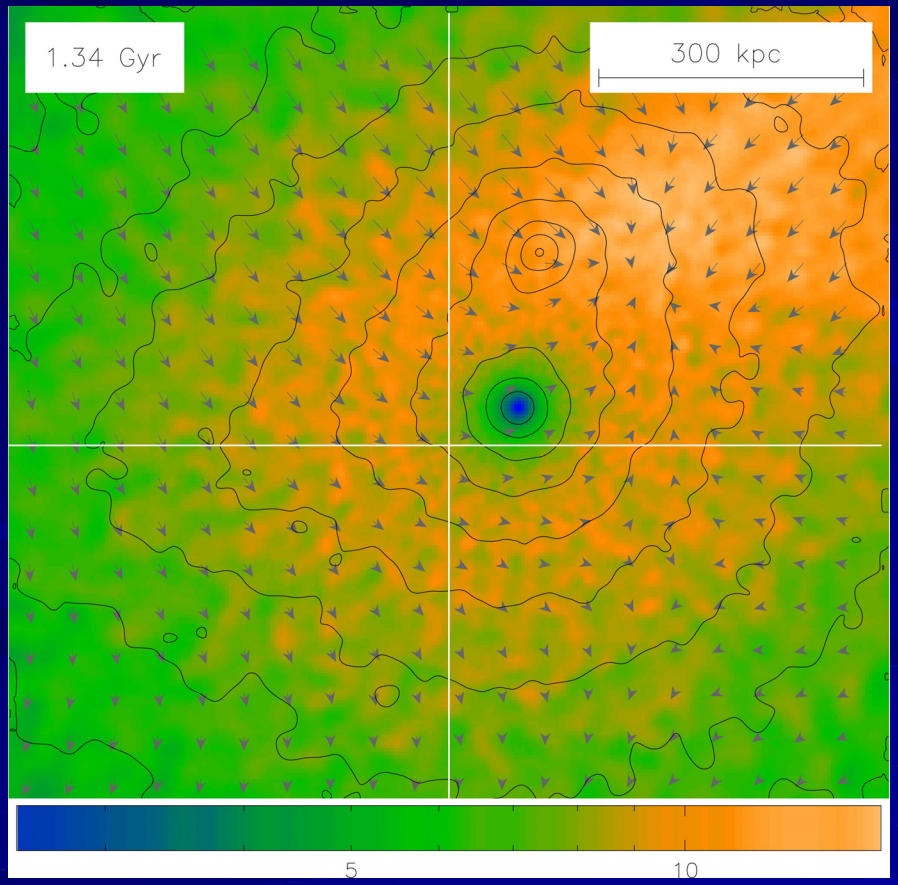
Velocity structure is generally complex, eg Abell 754 simulation, Roettiger et al. (1998; 3.1 & 6.7 keV clusters merge).

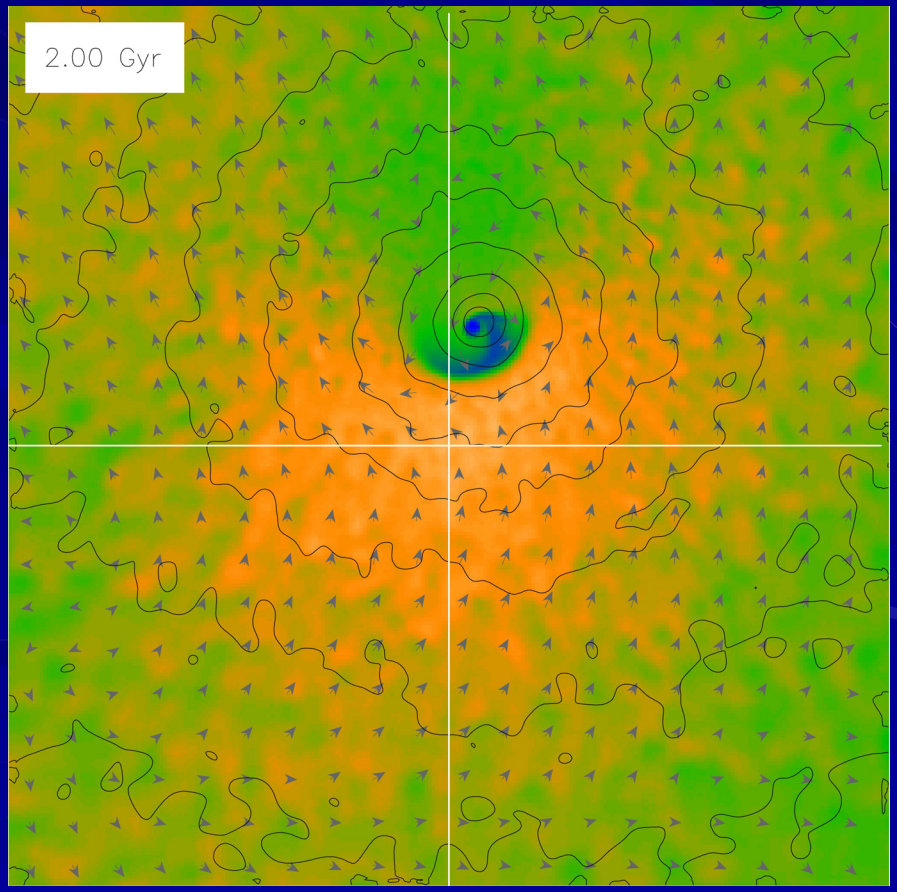
Minor Mergers & Sloshing

Minor mergers cause “sloshing” and cold fronts.

Velocity differences smaller than for major mergers (~few hundred km s^{-1}), eg Ascasibar & Markevitch (2006)

Good models will relate density, temperature and velocity structure - give estimates of associated heating rate.





Rotational Support

Clusters, groups and elliptical galaxies are not expected to have strong rotational support, but the distribution of angular momentum is broad ($\lambda \sim .05$, eg Bullock et al 2001).

Rotation speeds can be a significant fraction of velocity dispersion (~hundreds km s^{-1}) – detectable with Con-X.

Rotation is difficult to measure using galaxies (eg Hwang & Lee 2007).

Moderate rotation detectable with Con-X.

Gas need not follow galaxies and DM.

Rotational support affects gas distribution.

Distribution of gas angular momentum provides a test of models for structure formation.

Rotation affected by angular momentum transport (effective viscosity).

Large-Scale Motion Around Clusters

Con-X can measure line-of-sight velocities of groups and clusters directly.

Map (1-d) velocity field around mass concentrations (rich clusters and superclusters) using X-ray emitting (ie most massive) substructure.

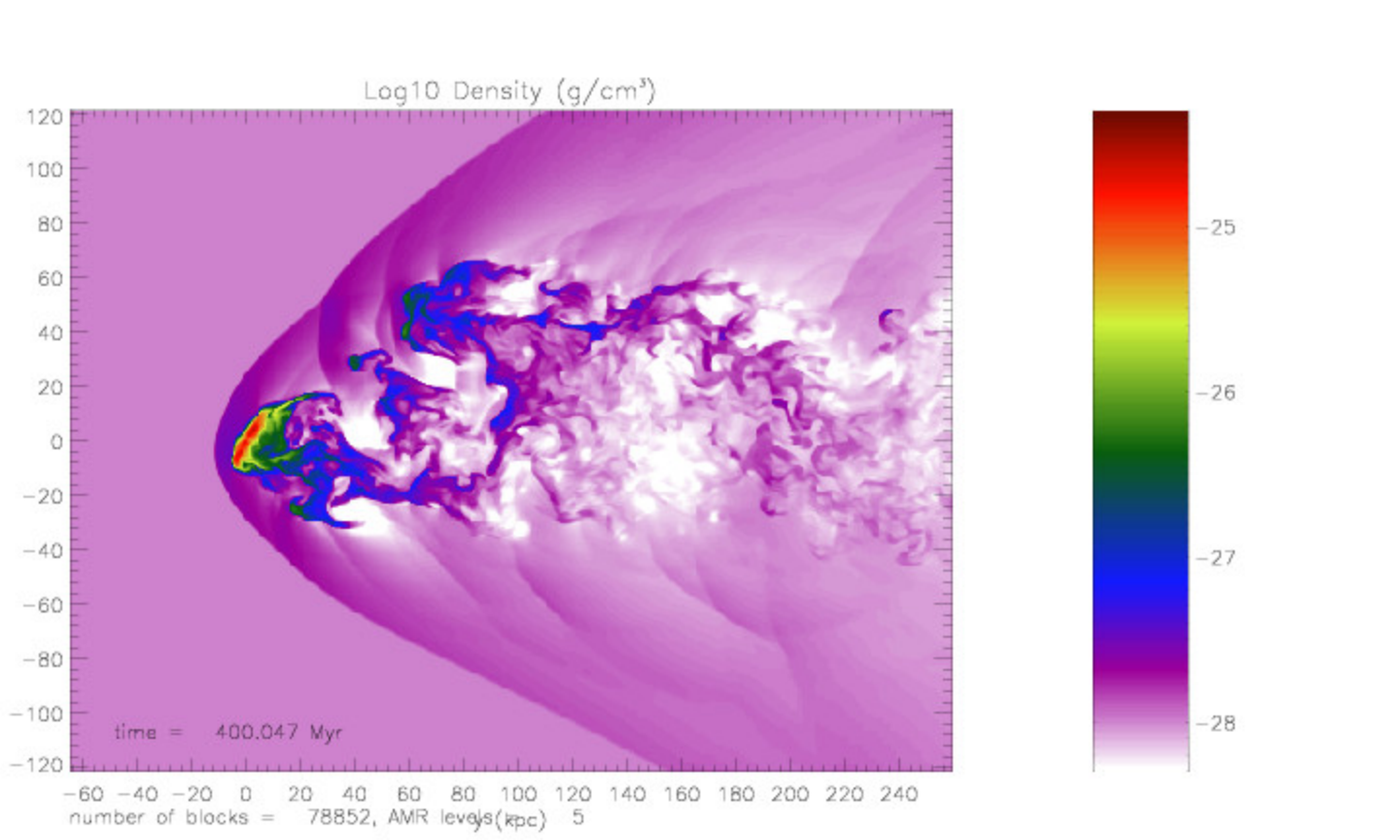
Relies on fewer, better defined mass concentrations than using galaxy velocities, should reduce ambiguities of location and membership.

Galaxy Stripping and Infall

Wakes produced by infalling galaxies can show significant velocity variations.

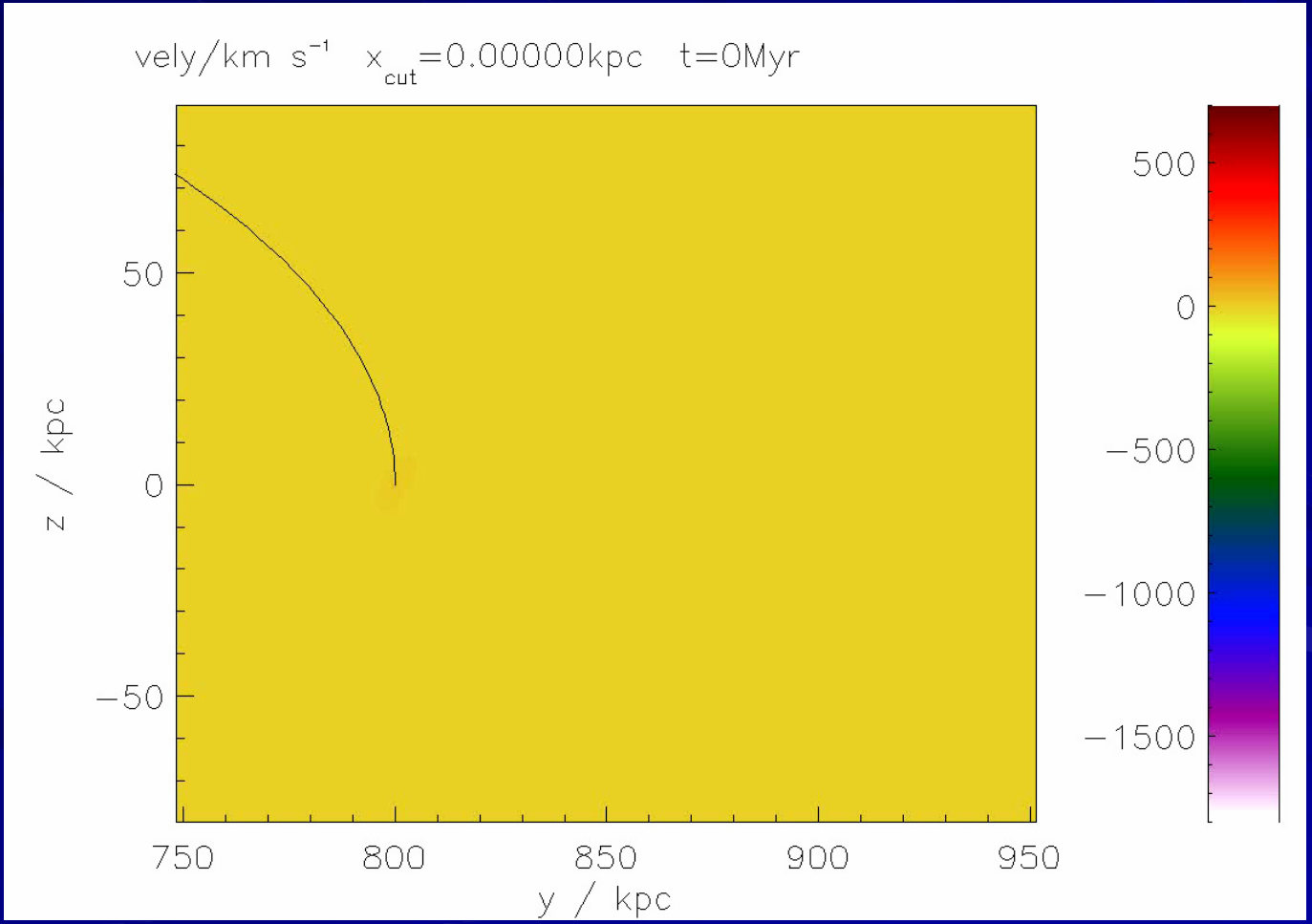
Should provide good test of stripping models (and transport coefficients).

Eg Roediger & Brüggen (2007 astro-ph/0712.0671), wake speeds ~few hundred km s^{-1}.

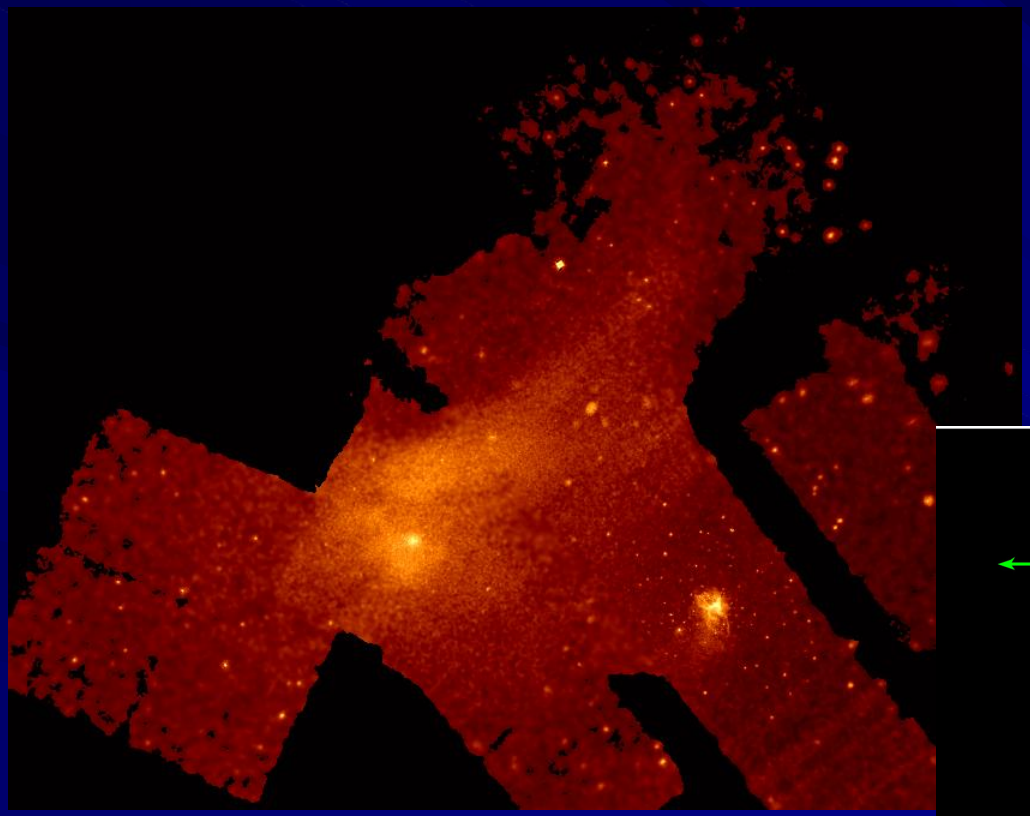


Stripping of a Disk Galaxy

One component of velocity for 10^{11} M_{sun} disk galaxy falling through a cluster (Roediger & Brüggen (2008).

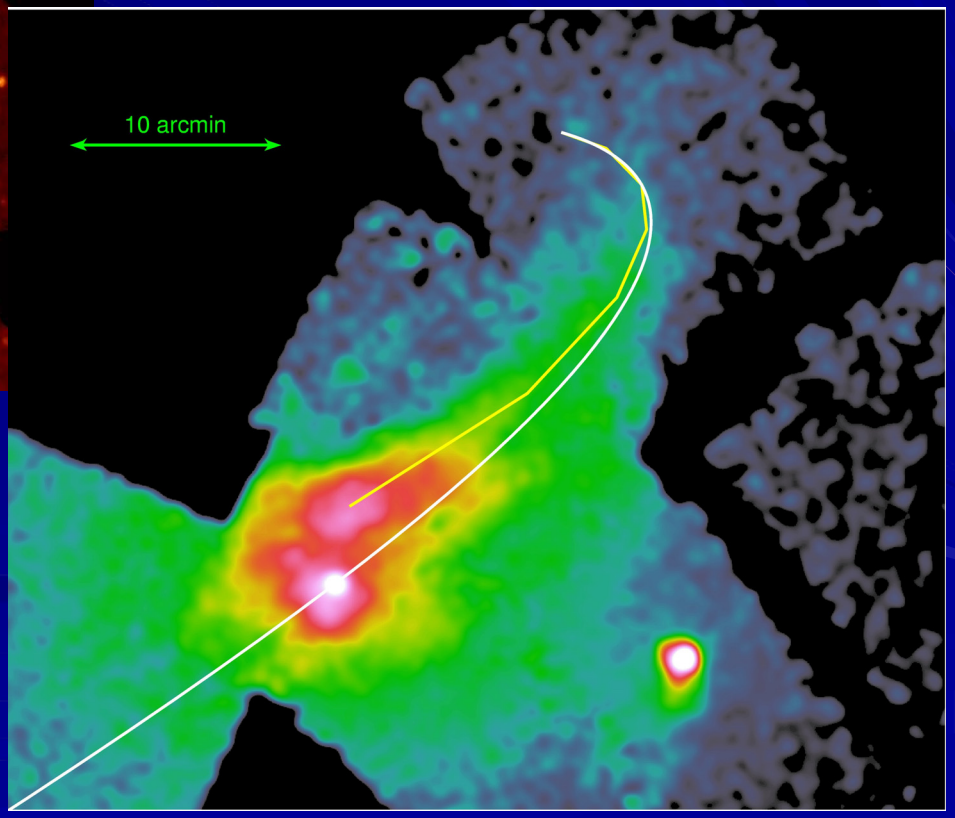


M86, Con-X Poster Child



M86 is approaching us at ~1600 km s^{-1} through the Virgo ICM.

Displaced blob and long tail of stripped gas, kT ~ 1 keV.



Simple model for stripping of blob -> moving few hundred km s^{-1} more slowly than M86 (Randall et al. in prep).

Velocity structure of stripped gas readily measured by Con-X.

History of X-ray Emitting Gas

Distribution of turbulence

Large-scale entropy distribution

Distribution of elements

Distribution of Turbulence

Measurements of velocity substructure (turbulence and bulk motion) with Con-X will clearly define the dynamical state of groups and clusters – relaxed vs unrelaxed.

Will assist in selecting clusters for use as cosmological probes (eg Allen et al. 2008).

Measurement of line width vs distance from a cluster center provides a test of the source of turbulence (mergers, wakes, AGN, etc.; Ruszkowski et al, in prep).

Distribution of turbulence can also constrain the effective viscosity (cf. Dolag et al. 2004).

Large-Scale Entropy Distribution

Large-scale gradients of the entropy reflect the history of entropy injection/heating of the ICM through mergers, AGN and galactic winds.

Deviations from sefl-similar behavior point to “preheating,” significant non-gravitational energy input (eg Voit 2005).

Is preheating uniform or confined to cluster cores?

Need low background.

Distribution of Elements

Details of the distribution of heavy elements on all scales in clusters will determine the history of enrichment – SNI, SNII, winds, etc (eg Loewenstein 2006).

Most of the gas lies at large radii, where abundances remain poorly determined.

Con-X will measure abundance anomalies in galaxy wakes in nearby clusters, quantifying that contribution to enrichment of the ICM (cf. Acreman et al. 2003).

Absolute Velocities

Direct measurements of recession velocity

- combine with transverse speed from kinetic SZ (eg Molnar & Birkinshaw 2001) to measure group and cluster peculiar velocities.

- requires accurate distances (SZ plus X-ray, eg Birkinshaw & Hughes 1994)

Summary

- Con-X could tell us a great deal about gas dynamics
  - major mergers, sloshing, rotation, large-scale motion, infall
  - calibration will matter
- It could determine the structure of cluster atmospheres on the large scales
  - turbulence, entropy, elements
  - low background to get largest scales
- Could measure group and cluster velocities directly